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Evaluation of Target Acquisition Difficulty Using Recognition Distance to Measure Required Retinal Area

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1. SUMMARY

The psychophysical method of limits was used to measure the distance at which observers could distinguish military vehicles photographed in natural landscapes. Obtained from the TNO-TM Search_2 dataset, these pictures either were rear-projected 35 mm slides or were presented on a computer monitor. Based on the rational that more difficult vehicle targets would require more visual pathways for recognition, difficulty of acquisition was defined in terms of the relative retinal area required for recognition. Relative retinal area was derived from the inverse square of the recognition distance of a particular vehicle relative to the distance of the vehicle that could be seen furthest away. Results are compared with data on the time required to find the vehicles in these pictures. These comparisons indicate that 1) the two methods are complementary with respect to distinguishing different degrees of acquisition difficulty; 2) recognition distance thresholds can be a suitable means of defining standards for the effectiveness of vital graphic information.

Keywords: vision, graphics, recognition, distance, retinal area, measurement, standards, target acquisition, TNO-TM Search_2

2. INTRODUCTION

2.1. Background

Graphic designers often contend that their work is too complex to be adequately represented by quantitative measurements of effectiveness. Yet the effectiveness of camouflage on military vehicles or the legibility of warnings on medications are examples where the effectiveness of graphic design has life and death consequences.

The power of the printed word led to a long history of quantitative research based on measurement of reading speed which has resulted in standards for the legibility of black letters on white backgrounds.[1,2] In an early attempt to extend such work to include color, Paterson &Tinker (1931) measured reading speed for words printed in various colors on various colored backgrounds.[3] They found that black/white were the most effective combination. A year later using the same colors, Preston, Schwankl & Tinker measured the effectiveness of colored print in terms of reading distance.[4] Blue/white, black/yellow, and green/white letter/background combinations were found to be the most effective. However, their results received little attention because subsequent replications using reading speed and recognition time continued to find black/white to be best while recognition time for other color combinations varied proportionally to lightness contrast.[2,5,6,7] This was seen as being consistent with vision theory that the middle and long wavelength based lightness-contrast mechanisms were the primary pathways for image detail.

Since color seemed to have no quantitative effect on legibility, its role in graphic design was presumed to be wholly a matter of aesthetic judgement. The results of Preston, et al. were conveniently forgotten. More recent contrary data on subjective legibility were ignored.[7] Also overlooked were data indicating different time constants of visual color mechanisms.[8,9] Convenience was probably another reason why most studies after the 1930's evaluated legibility using time measurements rather than distance.

Yet tachistoscopic presentations are not representative of reading tasks in the market place. Asked to measure the legibility of health warnings printed in color on tobacco packages, Nilsson & Percival reasoned that measuring legibility in terms of distance made more sense from a consumer's perspective.[10] However, greater distance did not adequately reflect subjectively greater ease of reading. Legibility was better described in terms of the required retinal image area based on the inverse square-root of distance. Subsequent research using distance to measure the effectiveness of foreground/background combinations of the six primary colors in messages, symbols, and outline drawings indicated that chromaticity contributed substantially to effectiveness.[11] This effect was not revealed when effectiveness was measured in terms of reading speed because chromaticity pathways are considerably slower than lightness-contrast pathways.

The effectiveness of camouflage depends on both color and pattern perception. Therefore, search time may not adequately reflect the contribution of color in recognizing such targets. The availability of the TNO-TM Search_2 dataset of high resolution images together with data on search time proved an opportunity to compare distance with time based measurements of visual effectiveness.[12] To help develop quantitative standards for more effective graphic design, this study evaluates data obtained by both methods.

2.2. Retinal Difficulty

The relationship between the distance at which a target can be recognized and the target's visual effectiveness is not as simple as might be supposed. When attention is directed at a target in a scene, the target's image falls on the foveal portion of the retina. Since the fovea has about one afferent neuron for every photoreceptor, the area of the target's image is proportional to the number of visual pathways available to convey information about the target. If all targets at

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recognition threshold produce the same critical amount of information in the afferent pathways, a target's visual effectiveness or difficulty can be measured in terms of the retinal area needed for recognition. The retinal area required for recognition in turn depends on the amount of information per unit area of a target's image. We'll define a visually effective target as one that provides enough information for recognition in a small retinal area. Conversely, a difficult target is one that provides enough information only when its retinal area is large. At recognition threshold, actual retinal areas need not be calculated to compare the targets in terms of how much information they provide. The ratio of their effectiveness or difficulty depends only on the ratio of their threshold retinal areas.

The area of a target's retinal image is proportional to the target's size and is inversely proportional to the square of its distance. Hold target size constant for the moment. A measurement of the maximal distance at which a target can be recognized is inversely proportional to the retinal area needed for recognition. A long threshold distance means a small retinal area and therefore represents a visually effective target. Conversely a short threshold distance must represent a visually difficult target. The ratio of their effectiveness or difficulty can therefore be determined by the ratio of their threshold distances squared. Since the present research concerned measuring the effectiveness of camouflage, a ratio that reflects difficulty of recognition was used. The target that was recognized furthest away was taken as the standard. Its small retinal area was set to a unit value "1". The retinal areas of all other targets at threshold were scaled as multiples of this unit value and the result for each called its *retinal difficulty*.

In practice, these calculations were easy. Due to the inverse relationship between distance and area, retinal difficulty was obtained by dividing the threshold distance squared of each target *into* the threshold distance squared of the target that was recognized furthest. As an example, assume that a certain difficult target, X, had a threshold distance of 2 meters and that the least difficult target, Y, had a threshold of 4 meters. How much larger is the retinal area of X compared to Y? The retinal area of X is proportional to $1 / 2^2$; the retinal area of Y is proportional to $1 / 4^2$. In finding the ratio of these proportions, their *proportional-to-actual-retinal-area aspects* cancel, and the result directly equals the ratio of their retinal areas. Representing retinal difficulty of target X as R_X, the proportional retinal area of targets X and Y as A_X and A_Y, and their threshold distances as D_X and D_Y, we have:

$$R_X = A_x / A_Y$$
$$= (1 / D_X)^2 \; / \; (1 / D_Y)^2$$
$$= D_Y^2 \; / \; D_X^2 \; = \; 4^2 \; / \; 2^2 \; = \; 4$$

The more difficult target requires 4 times the area at recognition threshold than the least difficult target. Accordingly X's retinal difficulty equals the value "4" compared to target Y.

What happens when targets differ in size? The answer involves the concepts discussed so far, but also requires some additional concepts including: *visage* - target size with respect to a plane perpendicular to the viewer. *retinal information density* - amount of information per unit area of the target's retinal image, and *usable information density* - a quantity which reflects the limit imposed by visual acuity. Taken into consideration, they explain such obvious matters as why a large image can be visually effective even though it has a low information density, or why it is harder to camouflage a tank than a jeep. It was considered premature to deal with these concepts here. In the present study, retinal difficulty of seeing the targets was measured only in terms of image distance. Target area was taken into account using graphic analysis to reveal its effect.

3. METHOD

3.1. Subjects

Subjects were recruited by posters on campus and consisted primarily of psychology majors in their 2nd and 3rd years of study. They were screened for normal visual acuity using a Snellen chart and screened for normal color vision using the Dvorine Test. The purpose of the experiment was explained. They were asked to respond when they could no longer recognize the target in the picture before them as a vehicle while the picture moved away and to respond when they first recognized the target as a vehicle while the picture moved towards them. They were given several practice trials to get acquainted with using the controls and making judgements. Three females and two males viewed slide projected images. Four males and two females viewed the images on a computer monitor.

3.2. Apparatus

The subject was seated at one end of an 8 meter test track in a long, completely black, dark room. A carriage riding on linear-bearings either carried a Kodak Ektagraphic 35 mm slide projector with a 2.5 inch lens projecting 155 cm onto an HP rear projection screen or carried a Dell/Sony D1025, 17 inch, color monitor with 1280 X 1024, 0.25 pitch display. A computer-controlled stepping-motor accelerated and decelerated the carriage at 5 cm/s^2 or maintained a steady velocity of 10 cm/s. Carriage position was continuously monitored by an independent optical-encoder and electronic register.

Operational safety was ensured by program interrupts, limits set in the dedicated motor controller, and an independent system of limit switches that operated a clutch and brake on the chain drive. The computer also recorded the measurements, signalled when the image should be changed, and waited for the subject's instructions. Control buttons enabled the subject to direct the computer to start a trial, read the distance, or repeat the present trial. Images were changed manually by a researcher who was present at all times.

3.3. Images

A Polaroid Sprint Scan 35+ made 35 mm slides from a CD-ROM disk containing Toet, Bijl, Kooi, and Valeton's TNO_TM Search_2 data set of high resolution (3072 X 2048 pixel) images of various military vehicles in mixed rural landscapes of green foliage and pale yellow grass.[12] The scanner was calibrated in terms of a Kodak color calibration slide included on the CD-ROM. Accuracy of color reproduction was tested with a Topcon BM-7 colorimeter. The Y, x, and y values for the eight saturated color patches from brown to blue correlated +.60, +.97, and +.77

respectively with the Kodak values. Generally smaller y values presumably represented short wavelength absorption by the screen. Gray scale reproduction correlated +.92 with the values on the slide.

In many of the slide-projected images, the vehicle was difficult to discern even when the image was moved close to the subject. In a few images, the vehicle could still be recognized near the far end of the track. Eliminating these left 27 slides that were tested. Non-uniformity of brightness (mean = 89 cd/m^2, sd = 38) across the central portion of rear-projected screen was a concern since vehicle position varied considerably. Viewing the CD-ROM images directly on a computer monitor produced a crisper appearance overall, but the images were smaller than the projected images. Therefore these images were enlarged four times with the vehicle approximately centered on the screen. Twenty-eight of the most suitable ones were selected for testing with the monitor. The Y value of the saturated color patches on the monitor correlated +.99 with the Kodak values, but the x and y values could not be measured for most colors. Gray scale correlation was +.92 .

3.4. Procedure

The method of limits was used to measure recognition distance thresholds for the vehicles in the images. A within-subjects, ABBA counterbalanced design determined the order of image presentation. Each image was initially presented close to the subject. The location of the target vehicle was pointed out or verified with the subject. When ready, the subject signalled the computer to back away the image. When the subject could no longer recognize the target as a vehicle, he/she signalled the computer to record the distance. The carriage kept moving back a fixed plus random distance and was then brought to a halt. The procedure was then reversed with the carriage moving forward until the subject could recognize that the target was a vehicle.

Ten such measurements were taken in succession and ten thresholds calculated using running averages. The two thresholds that differed most from the mean were dropped and the mean and standard deviation of the remaining eight were recorded. All images were tested in single sessions that lasted between 90 to 120 minutes. Subjects rested between images, could take a longer break when they wanted, and were asked to rest a few minutes midway through a session. The two orders of presentation were tested on separate days. At the end of the last session, all subjects who viewed the monitor pictures were asked to look at each picture again at a distance about 0.2 meter and rate how difficult it was to see the vehicle using a ten-point scale.

4. RESULTS

4.1. Slide-Projected Images

Table 1 at the end of this paper provides the mean threshold distances and standard deviations for the subjects who viewed the slide projected images. *Up* and down refer to the order in which the images were tested. Results for each image were averaged across subjects. As explained in Section 2.2, each image's *retinal difficulty* was calculated on the basis of its mean threshold distance and the threshold distance of image #34, whose vehicle could be recognized farthest away.

Figure 1 shows retinal difficulty of the 27 slide projected images that were tested. The images are arranged in decreasing order of target size based on Toet et al.'s report.[12] Images were arranged in order of decreasing target size to reveal the effect of target area. For comparison, Toet et al's search time for these targets is also shown. Not surprisingly, both retinal difficulty and search tend to increase as target size decreases. Retinal difficulty correlated -0.69 with target size; search correlated -0.43. The correlation of the retinal and search results was +0.80. For the larger targets on the left, retinal difficulty increases faster with decreasing size than does search time. Compared to search time, retinal difficulty was notably larger for images number 20, 16, and 30. In each of these the vehicle is well outlined against its background and discernable features. Image 2 was noted for taking longer to find than might be expected from its retinal difficulty. Though the target in image 2 blends well with the background, the reader should bear in mind that its location was indicated to subjects doing the distance viewing.

For further insight into how the distance and time measurements differ, the effect of target size on difficulty was removed. The relative value of the reciprocal of target size was subtracted from relative values of retinal difficulty and search time. The results were then restored to retinal difficulty and search time values. Figure 2 shows retinal difficulty and search time results with the image area factor removed. Both functions have lost their generally upward trend as target size decreases. Yet various images such as numbers 16, 20, 30 , and 2 continue to differ substantially in recognition difficulty using either retinal or search measurements.

To help identify where the two sets differ, the images were arranged in order of increasing difference between the retinal and search measurements. These results are shown in Figure 3. This reveals that for most of the images there was marked correspondence of changes in both retinal difficulty and search time, even when the measurements differed somewhat. Comparison of those images that produced similar effects with those that differed revealed no systematic characteristics related to these trends.

Both the distance threshold and the search time measurements were tested for the significance of the differences between their means using Duncan's test. The results are shown in Figure 4. The means for distance threshold and for search time are arranged in decreasing order to represent increasing difficulty of recognition from left to right. The horizontal lines below or above the image numbers indicate the images that do not differ significantly. Generally, distance thresholds effectively distinguished targets that are easy to recognize while search time is poor at distinguishing these same targets. To a considerable extent the opposite seems to hold for images that are difficult to recognize. Of the 32 pairs of images whose search times did not differ significantly, only one pair, 10 and 18, had distance thresholds that did not differ significantly. Of the 21 pairs whose threshold distances did not differ significantly, four pairs, 10-20, 36-42, 38-32, and 29-26, did not differ in their search times.

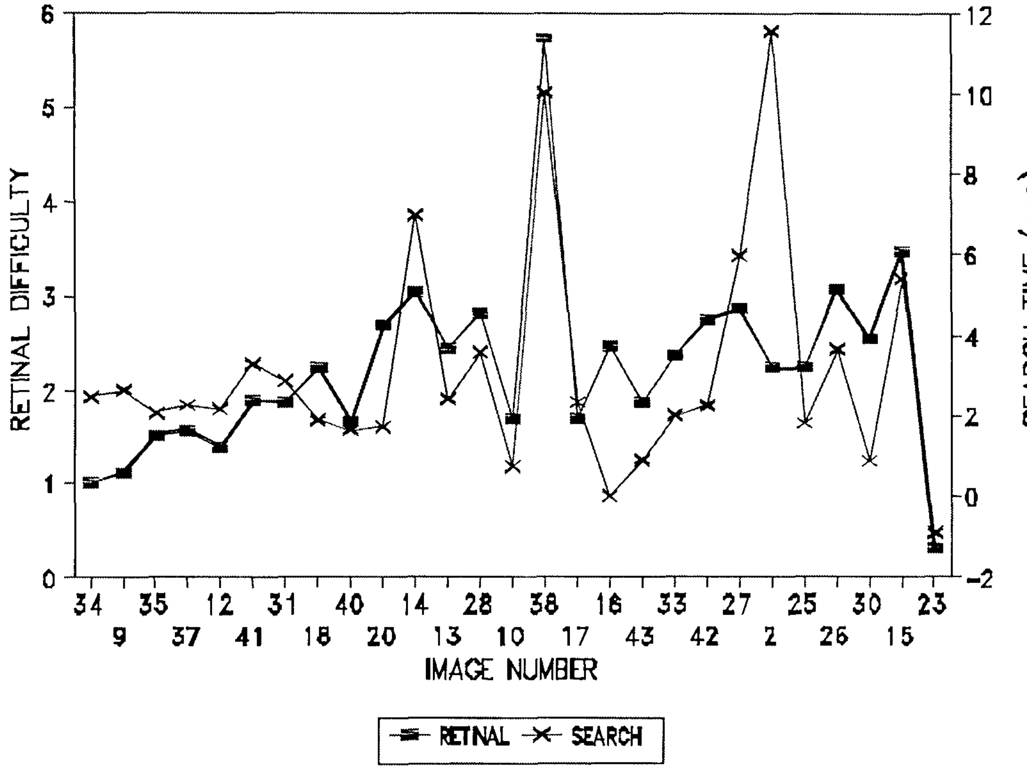

Figure 1. Retinal difficulty and search time of images that have been arranged in order of decreasing target size.

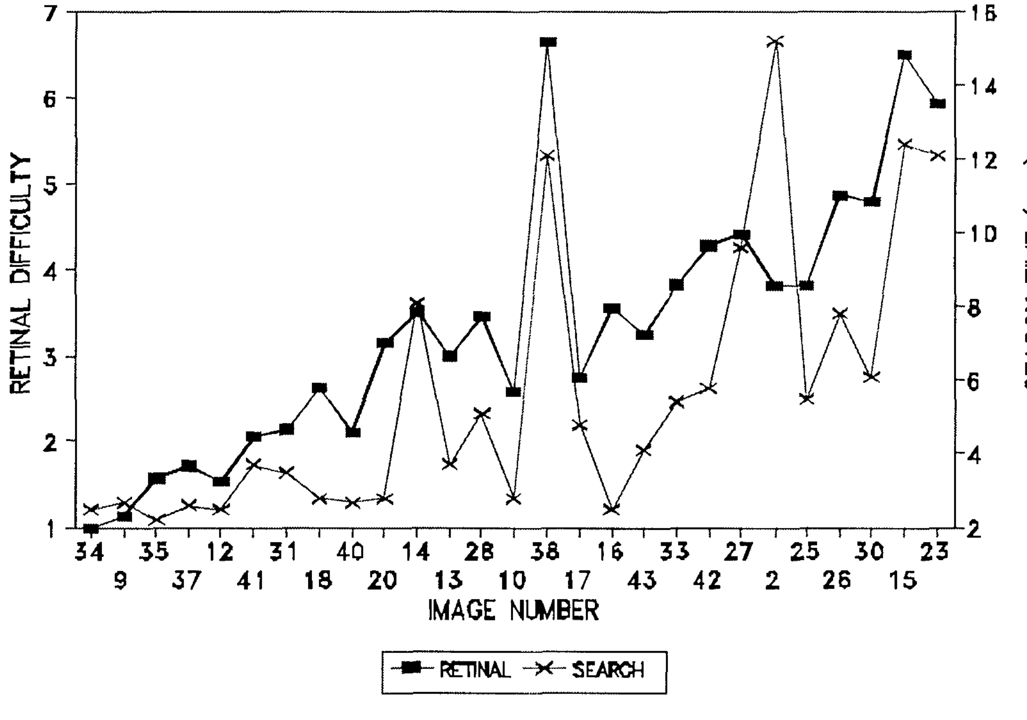

Figure 2. Retinal difficulty and search time with target size effect removed. The images arranged in order of decreasing target area.

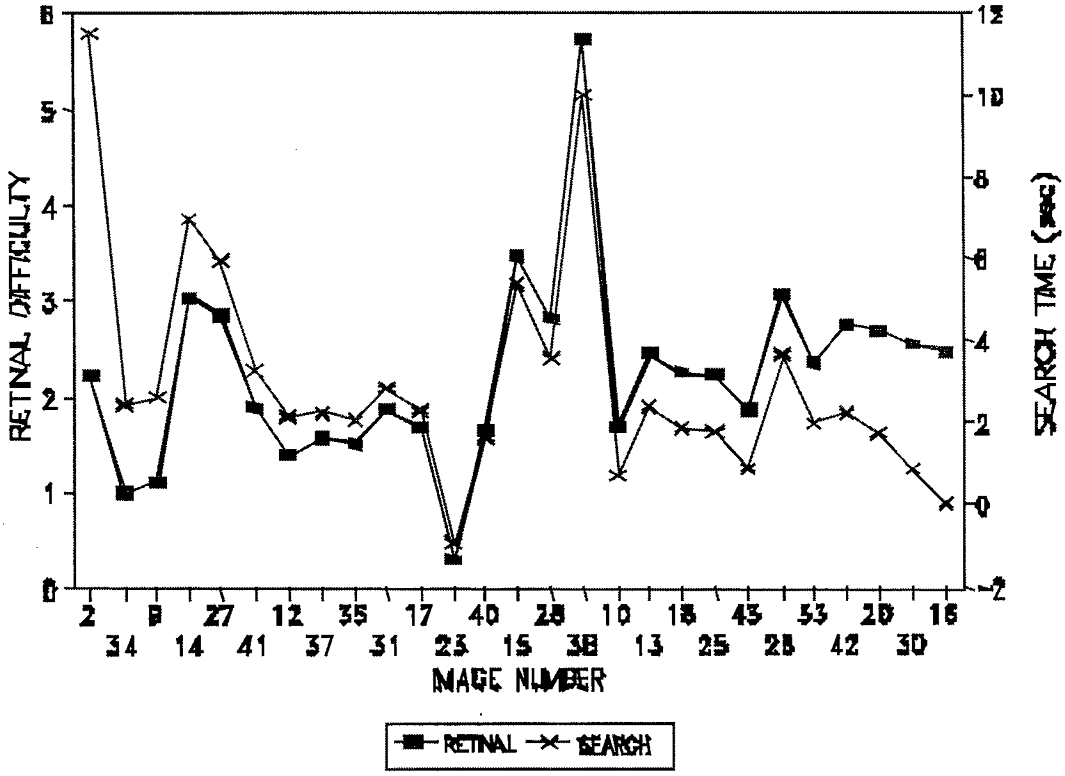

Figure 3. Images in Figure 2 rearranged to increasing difference between their retinal difficulty and search time

SEARCH TIMES

time (sec)	2.2	2.5	2.5	2.5	2.6	2.7	2.7	2.8	2.8	2.8	3.5	3.7	3.7	4.1	4.8	5.1	5.4	5.5	5.8	6.1	7.8	9.1	9.6	12.1	12.1	12.4	15.2
IMAGE	35	12	34	16	37	9	40	18	20	10	31	13	41	43	17	28	33	25	42	30	26	14	27	23	38	15	2

EASY DIFFICULT

IMAGE	34	9	12	35	37	41	40	31	10	18	17	13	20	43	28	14	16	2	25	33	42	27	30	26	23	15	38
distance (cm)	436	408	351	348	333	304	299	298	271	269	262	252	246	242	234	232	231	223	223	223	210	207	199	198	179	171	169

DISTANCE THRESHOLDS

Figure 4. Results of Duncan's test on the significance of differences between mean threshold distances and between mean search times.

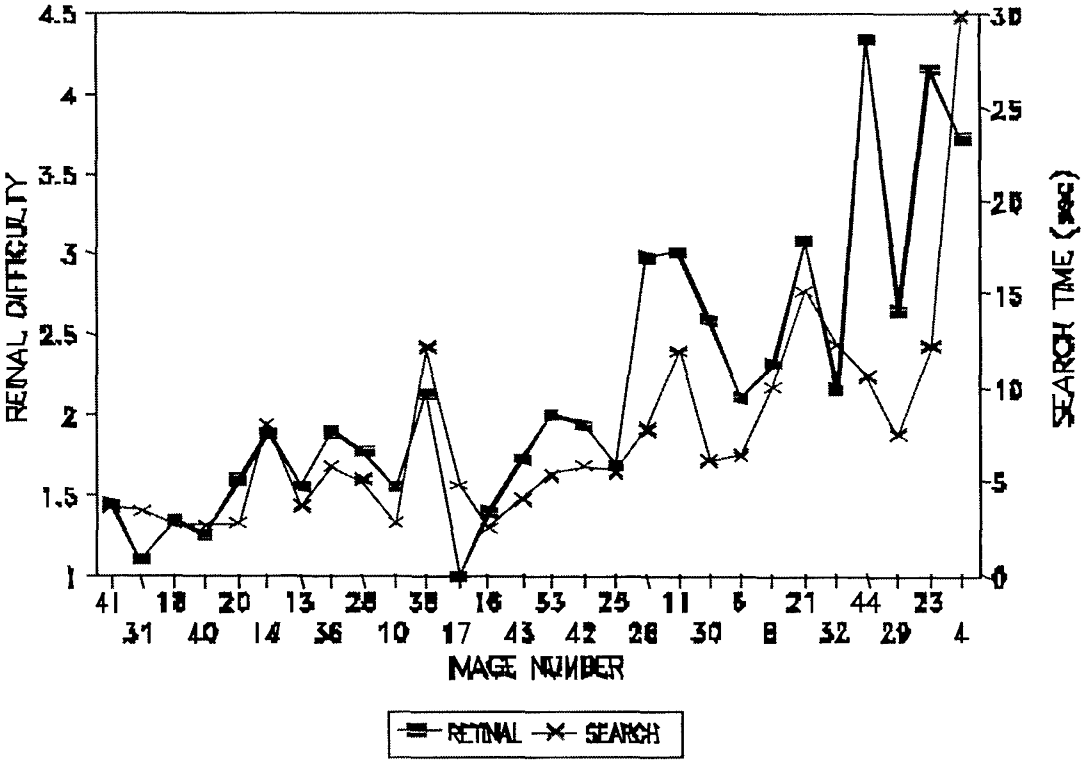

Figure 5. Retinal difficulty and mean search time for recognizing the targets in the various images presented on a monitor. Images are arranged in order of decreasing target size.

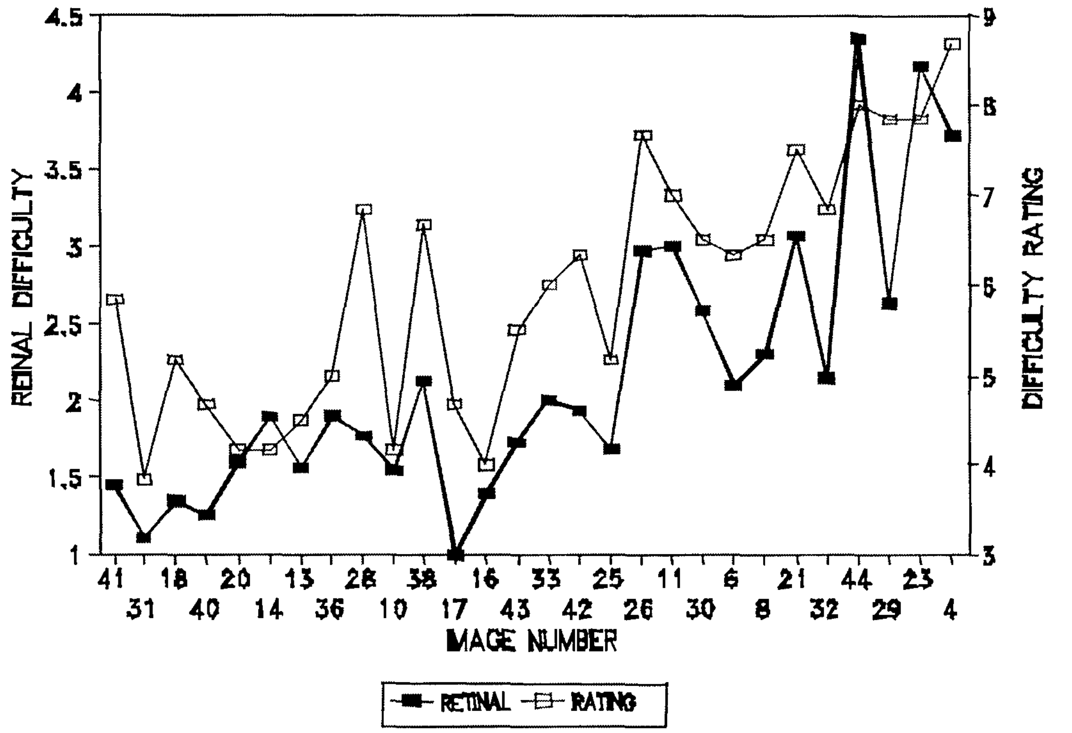

Figure 6. Retinal difficulty is compared with the mean rating of subjective difficulty of seeing the vehicle in each image. Images are arranged in order of decreasing target size.

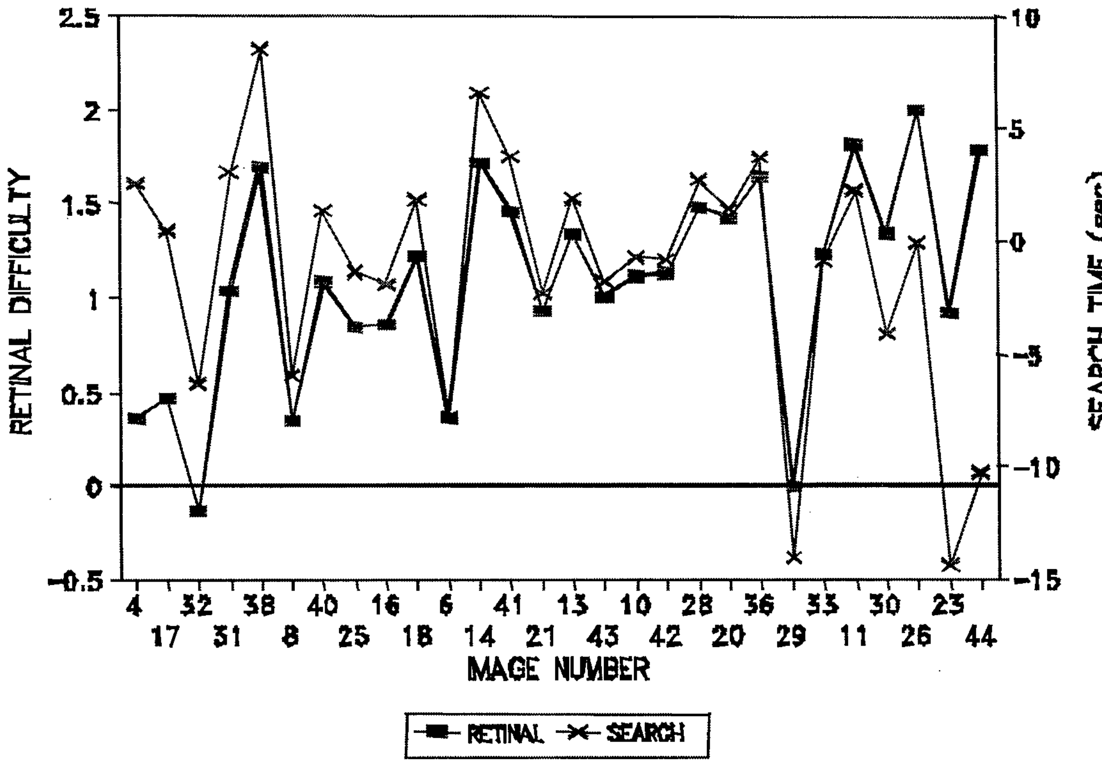

Figure 7. The effect of size has been removed from retinal difficulty and from search time. The results are plotted with the images in ascending order of difference between the two measurements.

SEARCH TIME

(sec) time	2.5	2.7	2.8	2.8	2.8	3.5	3.7	3.7	4.1	4.8	5.1	5.4	5.5	5.8	5.8	6.1	6.4	7.5	7.8	8.1	10.0	10.6	11.9	12.1	12.1	12.3	15.1	29.8
IMAGE	16	40	20	10	18	31	41	13	43	17	28	33	25	42	36	30	6	29	26	14	8	44	11	23	38	32	21	4

EASY DIFFICULT

IMAGE	17	31	40	18	16	41	10	13	20	25	43	28	14	36	42	33	6	38	32	8	30	29	26	11	21	4	23	44
distance (cm)	326	310	291	281	275	271	262	260	258	251	248	245	237	236	234	230	225	223	222	215	202	201	189	188	186	169	160	156

DISTANCE THRESHOLD

Figure 8. Results of Duncan's test on the significance of differences between mean threshold distances and between mean search times.

4.2. Monitor images

The threshold distance data for these images are provided in Table 2 at the end. As was done with the slide projected images, the distance thresholds for each of the 28 images tested were averaged across observers and converted to *retinal difficulty* values. The results are plotted in Figure 5 with the images arranged in descending order of target size. For comparison, the search time results measured by Toet et al. for these images are also shown. As target size decreased, both retinal difficulty and search time tended to increase. Retinal difficulty correlated -.61 with target size and search time -.49 with target size. As happened with the slide images, the two functions appear to track each other closely. Except for the smallest target, 4, subjects making distance threshold judgements had more trouble with the small targets (23, 29, 44) than those for whom search time was measured. The target in image 4 lacks both a distinctive shape, due to its head-on orientation and lack of contrast with its background. Targets 23, 29 and 44 have ample background contrast and have cues to their shape revealed by shadow and high-lights on the vehicles. Nineteen of these images were enlargements from the same images tested as projected slides. The correlation of the two sets of measurements was +.79.

For more information about the distance thresholds, retinal difficulty was compared with the ratings of subjective difficulty that were made by the subjects in the present study who viewed the images on a monitor. Figure 6 shows retinal difficulty and the mean ratings of subjective difficulty plotted as a function of decreasing target area. The two sets of measurements correlate +.85. The most notable differences again involve small targets in images number 23 and 44, which had relatively larger retinal difficulty values than subjective ratings. A similar difference was found above when the retinal difficulty of these targets was compared to their search times. On the other hand, the largest target in image 41 and a medium sized target in image 28 were rated notably more difficult than their retinal difficulty. While large, the target in image 41 is partly obscured by a tree and sits in the vicinity of other complex outlines produced by dark tree tops against pale grass. The vehicle in image 28 happens to line up with a light to dark transition across most of the scene. The subjective ratings correlated less well with search time, $r = +.72$ than did retinal difficulty, which is understandable since the latter involved the same subjects.

To see how differences between retinal difficulty, search time, and difficulty ratings were related to the size of the targets, the effect of target size was removed as was done with the data for projected images. Figure 7 shows the results for retinal difficulty and search time with the images arranged in order of difference between the two results. The biggest differences between the two types of measurement occurred for the images at each end of the graph depending on whether the search time (on the left) or retinal difficulty (on the right) had the larger value. As was noted when the size effect was not removed, the two types of measurement still differ most for images 4, 23, & 44. Removing the effect of size substantially reduced their correlation from +.72 to +.52. Removing the size effect did not change the correlation between retinal difficulty and the difficulty ratings.

Significance of the difference between means of distance thresholds of the images presented on a computer monitor was calculated using Duncan's test. The results are compared with those for the mean search times of these images in Figure 8. Of the 26 image pairs that did not differ significantly in search time, only 3 (42-36, 29-26, 38-32) did not differ in threshold distance. Similarly of the 21 image pairs that did not differ in threshold distance, 3 (10-20, 38-32, 29-26) also did not differ in threshold distance. Distance thresholds were somewhat better at distinguishing the easier images; search time was better for the more difficult images.

5. DISCUSSION

What do recognition distance thresholds reveal about the targets to be recognized? Target size had a substantial effect on both the distance and time based measurements of visual recognition. This can be seen in Figures 1 and 5 by the general increase in retinal difficulty and search time with decrease in target size. For the slide-projected images, retinal difficulty correlated -.69 with size, and search time correlated -.46; for the monitor images, the correlations were -.61 and -.49 respectively. The higher correlations of retinal difficulty with target size are understandable given the interaction between size, distance, and retinal area. While statistically significant (for 27 or 28 pairs, minimum significant $r = .38$) these correlations leave nearly 60% of the variance undetermined by the distance measurements. Some of that variance was due to measurement error. Despite the error arising from intra- and inter-observer variability, Duncan's tests revealed that a majority of the adjacent distance thresholds differed significantly. To what extent did these distinctions depend on target size which interacts with distance to determine the area of the retinal image? This is revealed in Figures 2 and 7, where the effect of size is removed from these measurements. Substantial variations in both retinal difficulty and search time as a function of the various images, indicate that other characteristics of the images influenced both measurement methods.

For additional insight into what other characteristics influenced these judgements, the effects of contrast were examined. The TNO-TM Search_2 data set provided measurements of the target vehicles' luminance and the surround luminance. From this a rough estimate of contrast was derived primarily based on the ratio between the dark area of the vehicle and the usually lighter grass. Retinal difficulty and search time correlated similarly with contrast (mean $r = -.35$ and -.37, respectively). Since these are not statistically significant correlations, this analysis indicates that it was not possible to estimate the contribution of contrast to recognition from these rough estimates. Research on colored symbols and backgrounds has found that chromaticity may contribute more to distance thresholds than does lightness contrast.[13] Chromaticity data were not available here, but their availability should be considered in future research.

Finally there is the effect of target shape. The vehicles generally appeared to have the most distinct shape when they stood sideways to the viewer. A rough estimate of the effect of shape was derived using the absolute value of a sine transformation of the vehicle's aspect angle in each image. For the slide-projected images, retinal difficulty and search time correlated -.39 and -.44 with this estimate of the shape effect; correlations for the monitor images were not significant ($r = -.25$ and -.28 respectively). The lower correlations of both retinal difficulty and search time for the

images viewed on the monitor were attributed to the different images in the two sets, since viewing conditions were constant for the search time data. The barely significant correlations with shape of data from the slide-projected images indicates that some of the differences in recognition were due to shape, but that aspect angle is not adequate for describing the effect of shape on these measurements.

How did the retinal difficulty measurements compare with the search time measurements? Evidence that the two methods were differently affected by target size is revealed in the results of the Duncan's tests in Figures 4 and 8. For both sets of images, threshold distances tended to distinguish larger targets better than smaller ones, while search times tended to distinguish smaller targets better than larger ones. Nevertheless, Figures 1 and 4 and show that both measurements of recognition difficulty generally increased with decreasing target size. This was also indicated by their significant, negative correlations with size as discussed above. However, many images were exceptions to this trend - some more so for retinal difficulty, others for search time. The two methods of measurement correlated +.80 for the projected images and +.72 for the monitor images. Since both measurements correlated substantially with image size, perhaps this explains their similarity. Removing the size effect reduced these correlations to +.61 and +.52 respectively. Note that the reduction was nearly the same for both sets of images. This similarity indicates that target size had a similar effect on both measurements. With the size effect removed, the results were arranged in order of the amount of difference between the two sets of measurements in Figures 3 and 7. In both figures, retinal difficulty and search time vary considerably as the images change. This indicates that differences other than the size of the images affected both methods of measurement. The close tracking of the two sets of results in both figures might lead one to think that two methods were similarly affected by these other characteristics. This was not the case. Reorganizing the results in terms of the differences does not change their correlations. Despite appearances, the pairs of functions in Figures 3 and 7 still have r values of only +.61 and +.52. Since Duncan's tests indicated a majority of the measurements were significantly different, the remaining variance was not all due to error. Evidently retinal difficulty and search time differed in how they were affected by other characteristics of the images.

Which method is better for distinguishing the difficulty of recognizing the vehicles? Duncan's tests indicate that threshold distances distinguished more images than did search time. For another way to address this question, subjects were asked to rate the overall difficulty of seeing the vehicle in each of the monitor-presented images. Figure 6 shows that the ratings increased more steadily with target size than did retinal difficulty. A comparison with Figure 5 shows this was also the case with respect to search time. Retinal difficulty correlated more strongly with the difficulty ratings ($r = +.85$) than did the search times ($r = +.72$). However, this is hardly a fair comparison since the search times were obtained from different subjects. Researchers studying the effectiveness of camouflage or other graphics should consider adding this simple measurement for comparison purposes.

Overall, the results obtained by Toet et al. and the present study indicate that the search time and retinal difficulty probably reflect different characteristics of the images. What does this imply for measuring the difficulty of recognizing camouflaged vehicles or, more generally, for measuring the effectiveness of graphics? Look again at the results from Duncan's tests in Figures 4 and 8. On average only 7% of the images that could not be distinguished by search time were also not distinguished by threshold distance, and 17% of the images not distinguished by distance were also not distinguished by search time. This suggests that the two measurements are indeed complementary. The use of both methods together would improve distinguishing camouflaged vehicles in terms of recognition difficulty. From a broader perspective, the favorable comparison with search time data on a standard set of images, provides further evidence that distance threshold measurements are an effective means of measuring the effectiveness of complex graphic displays.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Sanders, S.S. and McCormick, E.J., *Human factors in engineering design*, McGraw-Hill, New York, 1993.
2. Tinker, M.A., *Legibility of print*, Iowa State University Press, Ames, Iowa, 1963.
3. Paterson, D.G. and Tinker, M.A., "Studies of typographical factors influencing speed of reading", *Journal of Applied Psychology*, 45, pp. 471-479, 1931.
4. Preston, K., Swankl, H.P. and Tinker, M.A., "The effect of variations in color of print and background on legibility", *Journal of General Psychology*, 6. pp. 459-461, 1932.
5. Knoblauch, K., Arditi, A. and Szlyk, J., "Effects of chromatics and luminance contrast on reading", *Journal of the Optical Society of America A*, 8, pp. 428-439, 1991.
6. Legge, G.E., and Rubin, G.S., "Psychophysics of reading IV. Wavelength effects in normal and low vision", *Journal of the Optical Society of America A, 3*, pp. 400-51, 1986.
7. Pastoor, S., "Legibility and subjective preference for color combinations in text", *Human Factors*, 32, pp. 157-71, 1990.

8. Courtney, S.M. and Buchsbaum, G., "Temporal differences between color pathways with in the retinal as possible origin of subjective colors", *Vision Research*, 31, 1541-1548. 1991.

9. Nilsson, T.H., 'The effects of pulse rate and pulse duration on hue of monochromatic stimuli', *Vision Research*, 12, pp. 1907-1921, 1972.

10. Nilsson, T.H. and Percival, T.Q., *Evaluating the legibility of tobacco health warnings with a method suitable for defining market guidelines*. (Report K302507), Health and Welfare Canada. Ottawa, 1989.

11. Nilsson, T.H. and Connolly, G.K., "Chromatic contribution to shape perception revealed in a non-temporal task using distance", in *Colour vision research: Selected proceedings of the International Conference, John Dalton's Colour Vision Legacy*, C. Dickinson, I. Murphy and D. Carden, Eds., pp. 197-206, Taylor and Francis, Bristol, Pennsylvania, 1997.

12. Toet, A., Bijl, P., Kooi, F.L. and Valeton, J.M., *A high-resolution data set for testing search and detection models*. (Report TM-98-A020). TNO Human Factors Research Institute, Soesterberg, The Netherlands, 1998.

13. Clements-Smith, G., Nilsson, T.H., Connolly, G.K. and Ireland, W., *Development of an industrial service utilizing new technology to optimize visual information displays for both human and machine vision*, (Report 9F006-2-0021) Canadian Space Agency, Ottawa, 1993.

Table 1. Mean distance thresholds (cm) and standard deviations for subjects viewing slide projected images.

1st	SM - up		JM -		GM - up		LH - up		PM - down	
image	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
2	256	20.1	410	24.4	188	15.2	241	8.4	149	6.1
9	648	3.6	574	13.7	313	43.6	284	5.8	370	5.3
10	430	15.3	319	15.7	143	11.9	242	12.8	106	5.1
12	570	17.3	588	10.6	241	23.8	455	18.8	223	1.3
13	453	21.2	297	8.8	153	4.7	352	21.1	148	3.0
14	224	31.4	309	9.5	153	7.4	331	9.4	97	3.2
15	116	4.6	290	12.2	98	8.5	325	3.0	94	5.2
16	421	13.0	270	4.9	164	5.0	306	6.6	118	3.2
17	448	14.6	433	20.4	130	2.6	335	10.2	131	5.6
18	351	10.7	493	22.2	176	9.5	325	21.4	121	1.9
20	442	7.4	393	6.4	152	4.0	246	17.5	111	5.5
23	172	14.1	299	5.4	123	5.5	247	23.4	132	2.5
25	320	35.8	298	15.6	165	9.5	247	7.0	136	3.0
26	140	13.6	284	7.7	123	9.7	313	12.8	146	5.1
27	166	3.9	281	3.0	139	7.4	291	18.6	175	7.3
28	372	30.8	279	15.0	140	4.4	379	11.0	110	3.3
30	247	18.3	309	13.6	92	11.3	307	15.0	129	3.5
31	495	16.3	401	5.3	209	10.0	205	10.6	215	11.2
33	440	13.6	298	5.6	112	8.6	225	17.1	105	5.3
34	549	42.8	630	19.1	468	8.8	262	12.9	472	7.3
35	316	8.5	599	3.1	303	29.9	336	10.9	255	4.5
37	385	16.7	445	12.3	212	40.2	509	10.4	246	4.0
38	144	5.6	302	11.4	107	5.0	200	9.0	98	4.0
40	218	18.0	447	7.7	125	8.7	362	16.5	182	9.6
41	283	11.6	349	17.3	137	4.1	350	21.0	217	5.4
42	150	6.8	272	8.2	110	6.1	302	20.6	162	4.9
43	137	7.9	340	4.1	123	8.3	278	19.4	146	5.1
2nd	SM -		JM -up		GM - up		LH -		PM - up	
2	197	20.9	272	2.5	157	14.7	214	4.0	147	9.3
9	510	6.5	490	8.3	340	20.8	268	10.3	284	2.6
10	362	14.7	486	10.1	167	12.8	217	5.0	240	3.5
12	231	18.8	512	2.2	280	11.4	158	3.8	253	6.2
13	150	4.7	387	2.5	188	6.3	223	3.8	165	3.2
14	189	22.5	444	5.1	152	12.8	199	2.0	227	2.7
15	116	9.7	321	16.7	79	3.2	141	5.4	129	1.3
16	182	9.9	351	2.6	152	3.7	166	9.1	182	5.0
17	212	37.2	307	4.5	178	5.0	246	2.6	206	16.9
18	254	15.9	415	13.1	168	10.4	191	13.9	193	6.8
20	255	13.6	364	10.8	178	15.7	171	17.3	146	2.9
23	202	34.3	200	11.3	80	7.9	172	4.6	163	2.5
25	179	9.5	296	6.6	158	15.1	244	12.2	185	3.2
26	117	2.4	342	14.7	107	4.1	252	16.2	151	3.0
27	172	17.9	258	3.6	137	2.9	292	10.1	160	5.3
28	132	5.7	295	1.4	133	13.4	282	6.7	215	4.5
30	63	3.6	299	10.9	147	6.5	249	13.4	149	5.5
31	156	6.7	418	17.6	235	9.2	337	19.3	309	5.4
33	113	6.1	319	3.5	151	7.7	231	17.5	234	19.3
34	191	6.3	493	3.4	477	18.9	417	30.5	395	2.6
35	104	12.2	509	2.2	360	24.1	379	12.2	316	9.7
37	297	8.5	508	5.9	287	15.1	205	1.7	239	8.9
38	87	6.9	342	6.6	120	14.3	145	4.8	147	2.9
40	446	9.9	511	5.5	214	18.6	269	20.5	218	8.9
41	446	6.1	503	5.7	184	5.6	313	21.1	254	3.6
42	179	9.4	437	9.9	158	12.5	157	5.1	179	5.7
43	197	6.2	443	9.7	242	26.0	291	14.3	219	14.0

Table 2. Mean distance thresholds (cm) and standard deviations for subjects viewing monitor images.

1st	TC - down		RM - down		PM - up		GM - up		BF - up		SL - down	
image	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
4	83	10.0	107	4.2	109	3.2	172	9.1	149	4.3	220	8.6
6	88	2.4	169	17.1	190	2.7	251	12.9	259	9.5	217	22.5
8	93	7.1	200	6.1	191	9.7	229	11.0	205	8.1	167	6.6
10	98	3.5	158	12.7	234	9.6	332	23.7	232	12.2	277	17.2
11	73	2.8	94	7.8	155	1.8	307	30.5	187	10.3	176	9.8
13	112	2.0	181	19.0	208	8.4	298	18.1	203	8.2	248	13.0
14	69	3.2	110	23.9	367	11.1	250	15.0	222	13.5	213	9.7
16	94	10.1	302	33.5	168	12.5	347	24.3	216	7.9	308	16.9
17	132	6.8	397	20.7	199	6.7	376	34.1	267	22.2	289	19.4
18	96	5.0	199	15.3	233	8.4	339	14.4	238	7.4	277	7.6
20	114	18.9	129	13.0	250	3.1	365	6.7	245	15.8	281	11.2
21	63	4.5	142	5.1	198	4.8	263	22.8	144	6.6	166	0.9
23	67	3.8	124	7.2	145	11.1	235	18.5	182	3.1	91	11.3
25	125	8.8	139	11.4	344	10.0	299	26.5	205	10.2	173	7.7
26	62	1.7	127	16.9	207	2.8	226	25.2	160	4.3	187	11.8
28	82	5.2	165	26.0	275	8.8	251	16.1	170	4.3	250	7.3
29	71	7.9	122	6.9	205	12.3	187	9.0	165	5.2	225	9.0
30	78	2.3	163	25.8	190	6.2	255	25.2	157	1.8	230	13.6
31	196	9.0	217	19.6	358	14.1	428	48.9	233	13.2	289	17.3
32	78	9.5	143	7.6	287	1.3	222	14.1	200	5.7	257	8.3
33	100	6.1	188	19.1	198	7.7	256	4.8	229	15.3	297	7.3
36	133	11.7	152	16.5	263	8.8	232	6.4	255	8.3	234	15.4
38	120	6.3	115	13.6	175	5.0	229	16.0	256	10.0	230	6.0
40	105	6.1	215	6.7	376	14.3	262	32.5	271	17.9	357	24.6
41	153	18.1	167	20.6	350	9.4	264	13.0	219	11.4	338	4.6
42	121	8.5	145	16.4	249	6.1	233	12.7	194	6.7	307	13.4
43	167	12.3	134	13.2	265	6.2	270	33.0	187	4.6	323	18.2
44	81	4.9	89	3.6	190	3.7	150	11.8	81	4.9	137	8.7
2nd	TC - up		RM - up		PM - down		GM - down		BF - down		SL - up	
4	108	11.1	134	7.1	138	4.0	199	15.8	236	17.5	373	13.9
6	159	12.0	169	13.0	246	10.4	345	16.1	325	10.6	278	20.8
8	148	12.7	172	11.1	242	9.6	338	13.2	313	15.1	276	21.0
10	224	8.5	199	16.6	302	4.0	405	31.9	295	14.1	386	12.9
11	115	4.0	119	6.9	189	10.4	368	30.0	221	7.5	252	30.9
13	199	12.4	224	16.8	242	4.5	425	22.7	324	20.3	462	41.8
14	117	7.1	196	10.7	212	6.0	380	25.8	318	5.8	385	17.8
16	220	6.4	216	8.7	278	4.7	409	13.5	291	8.1	451	27.7
17	265	8.4	366	27.5	309	1.6	502	11.4	307	18.5	500	25.6
18	281	9.8	235	12.5	241	8.6	391	21.5	328	23.8	511	43.6
20	230	9.5	221	11.8	217	5.0	349	10.1	292	12.5	400	14.0
21	125	7.3	243	26.5	132	4.7	246	25.3	195	8.4	316	5.4
23	90	5.1	185	16.0	174	8.4	150	6.0	245	5.8	226	19.1
25	358	16.7	220	8.1	251	8.3	315	29.1	237	14.7	342	15.1
26	130	14.3	214	19.8	209	8.8	242	26.8	218	8.6	285	16.2
28	152	14.7	322	15.8	293	10.8	301	24.0	248	6.3	428	26.6
29	184	25.5	196	16.4	212	5.9	220	15.6	257	4.0	363	21.6
30	106	11.0	181	9.1	250	8.3	302	14.3	226	13.1	291	16.6
31	238	11.0	310	5.5	348	5.8	436	16.7	232	10.2	440	26.7
32	162	6.9	141	14.6	291	13.2	323	19.6	240	9.9	321	21.3
33	216	21.7	184	30.0	203	4.4	283	8.9	246	7.5	364	17.4
36	238	21.2	191	16.5	247	12.5	316	37.3	249	5.6	326	25.0
38	277	27.1	157	20.7	193	2.7	341	23.3	279	10.7	305	18.1
40	125	10.9	420	23.3	258	4.5	362	19.1	297	9.4	442	21.5
41	219	18.4	237	26.8	359	7.7	332	13.9	249	9.1	359	10.6
42	122	12.2	302	14.0	247	6.1	231	17.8	259	10.0	397	28.5